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DEVELOPMENT OF A SAFETY AND REGULATION SYSTEMS SIMULATION PROGRAM II

by

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REPORT

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under contract to the Atomic Energy Control Board

ABSTRACT

This report describes the development of a safety and regulation systems simulation program under contract to the Atomic Energy Control Board of Canada. A systems logic interaction simulation (SLISIM) program was developed for the AECB's HP-1000 computer which operates in the interactive simulation (INSIM) program environment. The SLISIM program simulates the spatial neutron dynamics, the regulation of the reactor power and in this version the CANDU-PHW 600 MW(e) computerized shutdown systems' trip parameters. The modular concept and interactive capability of the INSIM environment provides the user with considerable flexibility of the setup and control of the simulation.

RÉSUMÉ

Ce rapport décrit la mise au point d'un programme de simulation pour les systèmes de sûreté et de régulation. Ce travail a été fait dans le cadre d'un marché avec la Commission de contrôle de l'énergie atomique du Canada (CCEA). Le programme SLISIM (abréviation dérivée de "Systems Logic Interaction Simulation": simulation des interactions logiques des systèmes) a été mis au point pour l'ordinateur HP-1000 de la CCEA pour opérer en milieu INSIM (abréviation dérivée de "Interactive Simulation": simulation interactive). Le programme SLISIM simule la dynamique spatiale des neutrons, la régulation de la puissance du réacteur et, pour cette version-ci, les paramètres du déclenchement d'arrêt contrôlé par ordinateur pour le réacteur CANDU-PHW 600 MW(e). La conception modulaire du milieu interactif INSIM donne à l'usager une grande flexibilité dans la préparation et le contrôle de la simulation.

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DEVELOPMENT OF A SAFETY AND REGULATION SYSTEMS SIMULATION PROGRAM II

A. INTRODUCTION

This project was done to assess the feasibility of developing a safety and regulation simulation program which would assist the AECB staff in its review of trip effectiveness for CANDU computerized shutdown systems. A Systems Logic Interaction SIMulation (SLISIM) program was developed to represent the physical and software interactions between the spatial neutron flux variations, the reactor regulation system and the reactor shutdown system trip parameters. The program runs in an INteractive SIMulation (INSIM) environment which provides the user with the flexibility to reconfigure his model or alter system parameters. The INSIM program is a proprietary operating system which had been developed by the Contractor and was used to develop and operate the SLISIM program. Simulation of the spatial neutron dynamics within SLISIM is based on the SMOKIN code (Ref. 1). Simulation of the computerized shutdown systems is based on the Programmable Digital Comparators (PDC's) used in the currently operating CANDU-PHW 600 MW(e) nuclear power stations (Ref. 2, 3, 4).

B. SYSTEM LOGIC INTERACTION SIMULATION (SLISIM) MODEL

1. System Model

The system model is constructed from a selection of the eight available modules. The modular nature of the program allows for expansion of the number of program modules.

1.1 System Modules

The present eight modules can be divided into two groups:

- group 1 comprises modules 1 to 6 which simulate the neutronic, regulation and shutdown systems.
- group 2 comprises modules 7 and 8 and simulates CANDU 600 MW(e) shutdown system # 1 and shutdown system #2 programmable digital comparators (PDC's).

1.1.1 Neutronic, Regulation and Shutdown System Modules

The six modules in this group are:

- Module 1 = SPANK
- Module 2 = SDS N.SIG
- Module 3 = SDS1-SOR
- Module 4 = SDS2-PI
- Module 5 = RRSC
- Module 6 = RRSD

(a) SPANK: this module simulates the spatial analog neutron kinetics and computes:

- neutron spatial dynamics,
- delayed neutron precursor concentrations,
- Xe and I concentrations and associated reactivity,
- power feedback reactivity,
- reactivities due to regulation and shutdown system devices.

(b) SDS N.SIG: this module simulates the response of the neutron sensors and computes:

- in-core neutron detectors' response,
- ion chambers' response,
- ion chambers' log rate,
- shutdown system #1 (SDS1) and shutdown system #2 (SDS2) channel trips by regional overpower trip (ROPT) and log rate trip parameters,
- SDS1 and SDS2 general and local coincidence logic trips.

(c) SDS1-SOR: this module simulates actuation of the shutoff rods (SOR) which comprise the final elements of SDS1 and computes:

- insertion of shutoff rods into the reactor core as a function of time after initiation of a SDS1 trip.

(d) SDS2-PI: this module simulates actuation of the poison injection (PI) system which comprises the final elements of SDS2 and computes:

- insertion of highly neutron absorbing liquid (poison) into the reactor core as a function of time after initiation of a SDS2 trip.

(e) RRSC: this module simulates the reactor regulating system devices whose motion is of a continuous nature. (reactor regulating system - continuous-RRSC). The module computes:

- positions of liquid zone level control valves,
- levels and volumes of H_2O in liquid zone controllers,
- positions of mechanical control absorbers (MCA's) and adjuster rods (AR's),
- position as a function of time for induced perturbations (refuelling, MCA's insertion, AR's).

(f) RRSD: this module simulates the action of the digital computer control of the bulk and spatial neutron flux. (reactor regulating system discrete-RRSD) The module computes:

- the bulk and spatial power errors,
- the bulk and spatial components of the liquid zone controller's valve lifts,
- response to requested power changes.

1.1.2 Computerized Trip Parameter Modules

The two modules in this group are:

- Module 7 = SDS1-PDC
- Module 8 = SDS2-PDC

(a) SDS1-PDC: this module simulates the software and hardware functions of the CANDU 600 MW(e) SDS1 programmable digital comparators (Ref. 2, 3). The module computes:

- the neutron signal conditioning of process parameters based on output from module 2*,
- trip setpoints for process parameters,
- channel and shutdown system trips by process parameters.

(b) SDS2-PDC: this module simulates the software and hardware functions of the CANDU 600 MW(e) SDS2 programmable digital comparators (Ref. 4). The module computes:

- the neutron signal conditioning of process parameters based on output from module 2*,
- trip setpoints for process parameters,
- channel and shutdown system trips by process parameters,
- inhibition of a SDS2 trip by the proposed power rundown discriminators.

1.2 Time Simulation

Scheduling and execution of the model's modules requires a capability for both continuous and discrete event simulation.

1.2.1 Continuous Time Simulation

The output of modules 1 to 5 is computed based on a continuous time simulation. The output at the selected times is integrated over the time interval. An exponential integration routine is used to simulate rapid changes while an Euler intergration routine is used to simulate slow changes such as those due to Xenon, Xe, and Iodine, I.

Output of modules 1 to 5 is computed at the same time value and uses the same time interval. Selection of module 1 sets the basic simulation time interval for the simulation. Smaller simulation time intervals for other modules are not allowed.

1.2.2 Discrete Event Simulation

The output of modules 6, 7 and 8 is computed based on samples taken at discrete time intervals. This discrete event simulation capability is required to simulate the:

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* If module 2 is not selected, default values for the neutron signals are used. These values can be changed by the user.

- bulk and spatial control of the neutron power by the stations' direct digital control computers which is simulated by module 6,
- SDS1's programmable digital comparators' software functions which are simulated by module 7,
- SDS2's programmable digital comparators' software functions which are simulated by module 8.

Capability is provided for input of different sampling intervals for: (a) both bulk and spatial control, (b) SDS1-PDC's and (c) SDS2-PDC's.

The asynchronous nature of the physical system is simulated by allowing the user to input a phase factor. This phase factor shifts the module's sampling interval relative to the basic time interval. For example with a basic time interval for module 1 of 50 m sec. and a discrete event sampling time interval of 100 m sec., the phase factor allows the first (and subsequent) time samples to be taken at times of 50 or 100 m sec. delay.

2. Program Structure

The SLISIM program had been developed to operate within an interactive simulation (INSIM) system environment. The main features of the INSIM program are its:

- modular structure,
- extensive user interactive simulation capabilities.

2.1 Modular Structure

The modular structured programming capability gives the user flexibility in selection of modules to create his model and to add additional modules if required. To preserve this modular independence, each module has its own separate input, output and parameter change and examine routines.

2.1.1 Input Data Files

Each module has its own input data file. These data files are considered to be the reference data bases. With separate data files for each module, the user does not have to edit the input data file each time he alters the number of modules in his model. Only the input data files for the selected modules are read by the program.

All available data on each of the files are read in. The user has the capability to alter these data after the final input data file has been read in. In the case of reactivity perturbation data, all the available perturbation data are read in but on completion of the read the perturbation initiations are disabled. The user selects from the available perturbations which one he wishes to initiate by enabling the corresponding perturbation.

Provision is made for the user to read in other data files by changing the default input file names on initial setup of the model.

N.B. The input data files for modules 7 and 8 contain not only the parameter values but also a physical description of the parameters and variables used by the module.

2.1.2 Initialization Routines

A common initialization routine is used for modules 1 to 6. This arises because of the interdependence of this group of modules. This initialization routine sets the initial values of the modules' variables and establishes the initial reactivity balance with the reactivity devices at their given position.

The initialization routines for modules 7 and 8, SDS1 and SDS2 PDC's respectively, set the module variables to their initial conditions.

2.1.3 Screen/Printer Output

The progress of the simulation is monitored through output of variable values to the screen and to a printer. Two different groups of 33 variables each but from the same common group of 177 can be output at a time interval selected by the user. Default values are provided for the two groups of 33 variables and the output time interval. These default values can be changed by the user any time during the simulation.

2.1.4 Module Output to File

The user can select output options from each module to a file. This output can be reviewed at any time during the simulation and supplements the screen/printer output.

Three output options are provided for each module which are:

- 0 = no output,
- 1 = partial output,
- 2 = full output.

The default value for each module is 0 but this can be changed for each module by the user during initial setup of his model.

N.B. Output options are established on initial setup of the model and cannot be changed during the simulation.

The user is given the option to change the output file name from its default name, SLIØØ1.

In addition to the above output, a standard SMOKIN type output is written to file SLSMO1.

2.2 User Interaction

The INSIM program provides a "user-friendly" operating environment through provision of:

- menus from which user makes selections,
- prompts,
- extensive error checking of user keyboard input,
- windowing features,
- and a keyboard interrupt capability which allows the user to interrupt the simulation at the end of a basic time cycle, change parameters and then continue with the simulation.

The above INSIM characteristics provide the SLISIM user with the following features:

- model generation from available modules,
- input data file selection,
- menu (option) selection on keyboard interrupt of simulation,
- prompting,
- keyboard input error checking.

2.2.1 Model Generation

On initial startup the user is queried whether the case to be simulated is a restart of a previously "saved" simulation. If YES, the user is prompted for the restart file name if it is not the default file name, SLIRS1. For a restart case, the modules used to generate the model are those that were used in the previous simulation.

If not a restart case, the user selects from the eight available modules, which are presented in sequence, only those needed to construct his model.

N.B. At present it is recommended the user select any one, two or all three of the following module sets:

- modules 1 to 6,
- module 7,
- module 8.

Provision exists for future modifications wherby the user can select module 1 and one or more of modules 2 to 6.

Following module selection the user is prompted for the input data file names for his selected modules, if the input data is on files other than the default files. (See following Section 2.2.2.)

During the initial setup, the user is prompted for selection of of an option for output of the values of the modules' variables to a file. (See previous Section 2.1.4.)

After initial selection of modules and output options, the user is presented with a summary of his model modules and the selected file output options. At this stage the user is given the option to change his option through a restart of the initial selection process.

2.2.2 Input Data File Selection

Reference data base files are provided for modules 1 to 8. These data files have been discussed in section 2.1.1. The user is provided with a capability to change the majority of the input data for the modules before the start of the simulation. However, these changes apply only to the current simulation and would have to be re-entered for each simulation. For simulations which require considerable changes to the input data, provision exists for the user to create a new data file and use this file as input instead of the default file.

2.2.3 Keyboard Interrupt Menu

The keyboard interrupt menu is displayed following each keyboard interrupt of the simulation and also following completion of reading the input data files for all the selected modules. This latter display of the keyboard interrupt menu allows the user to change module parameters prior to module initialization and start of the simulation.

The available keyboard interrupt options are:

Option	Item
1	Change input parameter values
2	Change printer output parameters
3	Change screen output parameters
4	Status of SDS1-PDC logical variables
5	Status of SDS2-PDC logical variables
6	Save for restart
7	Examine value of variables
8	Review variable history
9	Continue with simulation
10	Stop Execution of code.

1. Change input parameter values: this option enables the user to change values of the modules' parameters. Selecting this option results in a layered menu, the first menu displays the modules from which the user selects the module whose variables he wishes to change. After selection of the module, the user is presented with the list of the module parameters which he can change. This routine is capable of changing module parameters which are identified by up to 3-dimensioned arrays.

N.B. If a simulation of a reactivity perturbation is required, the user has to specify the type of perturbation to be initiated by this "change input parameter" routine.

2. Change printer output parameters: this option allows the user to change the printer output time interval*, the phase factor (see Section 1.2.2) and the variables that will be output to the printer. The user can select any 33 variables from a list of 177. A default list is provided which can be altered by the user. This capability allows the user to select the format (row and column) for presentation of the variables as the list of 33 can be selected in random order from the available list of 177.

3. Change screen output parameters: this option parallels option 2 and allows the user to change the screen output time interval*, the phase factor (see Section .12.2) and the variables that will by output to the screen. The user can select a group of 33 variables (a group which is distinct from the group of 33 printer variables) from the list of 177 variables which is a common selection list for both the printer and screen selection sets.

4. Status of SDS1-PDC logical variables: this option reviews the status of all logical variables and displays on the screen those which are TRUE along with the array name, element number and physical description of the variable. It should be noted that the normal state, except for a few variables, is FALSE. The variables initially set to true can be determined by requesting this option before the start of the simulation.

5. Status of SDS2-PDC logical variables: this option is identical to option 4 but presents the status of SDS2-PDC logical variables which are set to TRUE.

6. Save for restart: this option allows the user to save the current status of his simulation. The simulation can be continued at a later time using this file as the input file.

7. Examine value of variables: this option allows the user to examine variables and parameters for the modules during the simulation. A layered menu structure and approach, common to option 1. (see option 1. above) is used. In addition to the parameters that the user is allowed to change under option 1., the user can also examine the values of the modules' variables.

8. Review variable history: this option allows the user to review the modules' output written to file (see Section 2.1.4). The number available for review at any one time is fixed at 30. This list can be composed of variables selected from the different modules. Successive review of different groups of 30 values can be accommodated.

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* The output time interval and phase factor are common for both the printer and screen output.

9. Continue with simulation: this option results in continuation of the simulation from its current status.

10. Stop execution of code: this option results in termination of the simulation and closure of files used during the simulation.

2.2.4 Prompting

The user is assisted in setup and control of the simulation by use of screen windows combined with prompt commands. Response to prompts can be of the following form:

- C/R, pressing "carriage return" leaves the default value unchanged or a keyboard entry to change the default parameter.
- a Y/N (Yes/No) response to a query.
- a specific response as defined in the prompt statement.

In addition to the prompts, messages are output to the screen to inform the user of the operational status of his simulation. These messages are in addition to the normal screen output (see section 2.1.3).

2.2.5 Keyboard Input Error Checking

Extensive error checking of user input from the keyboard is incorporated into the program. Input variables are checked for type and array variables are checked for range. This reduces the probability of inadvertently changing module variables or inputting data which could disrupt the simulation. Furthermore, most keyboard input changes are echoed on the screen to the user for verification. If the wrong value was entered, the user can input the correct change.

3. Simulation Modules

The SLISIM program modules can be divided into two groups which are those simulating:

- the neutron spatial dynamics, the reactor regulation system and the shutdown systems' final elements,
- the shutdown systems' computerized trip parameters.

3.1 Neutron Spatial Dynamics, Reactor Regulation and Shutdown Systems

These systems simulated are those for the Ontario Hydro Bruce 'A' nuclear reactor. This arose because the version of the SMOKIN code and data provided to the Contractor were those for the Bruce GS 'A' reactor. Modules 1 to 6 simulate the above systems, with a restricted simulation of the shutdown systems as was provided.

3.2 Shutdown Systems' Computerized Trip Parameters

Modules 7 and 8 simulate the CANDU-PHW 600 MW(e) SDS1 and SDS2 programmable digital comparators respectively. The three channels and the two programmable digital comparators for each channel for each of the two shutdown systems are simulated. The linear and log ion chambers and the in-core detector signals used for the required neutron power conditioning are obtained from module 2.

3.3 Simulation of Other Systems

Other reactor core, regulation, shutdown systems and their associated software can be simulated.

3.3.1 Neutron Spatial Dynamics, Reactor Regulation and Shutdown Systems

The minimum changes required would be changes to the input data files for modules 1 to 6 to reflect the parameters of the physical system. In addition, programming changes could be required to module 6, the simulated computer control program which regulates the spatial and bulk neutron flux, if an accurate simulation is required of the new system which has different controllers.

3.3.2 Computerized Shutdown Systems

Simulation of computerized shutdown systems for reactors other than the CANDU-PHW 600 MW(e) reactors could require extensive programming changes to modules 7 and 8, their replacement by new modules or incorporation of additional modules into SLISIM.

3.4 Operating Environment

It was originally thought that the required simulation program would be developed based on the ANEVENT/HYSTAN operating environment. On further study it was found that the ANEVENT/HYSTAN variable identification structure if used for all modules would be too cumbersome to the user. The structure, allowing easy access to the variables, allows identification of the variables as real, integer or logical only, with any further identification by four digits rather than a mnemonic representation. Also, transferring ANEVENT/HYSTAN from the VAX computer to AECB's HP-1000 with its reduced capability could present difficulties which would require considerable effort by the AECB's computer staff to overcome. Furthermore use of ANEVENT/HYSTAN on the National Research Council's VAX computer to develop the required simulation program would result in considerable communication costs.

INSIM, developed by the Contractor, would provide a superior or at least an equivalent operating environment to that of ANEVENT/HYSTAN on the HP-1000. INSIM incorporates also the latest interactive and "user-friendly" features. Therefore it was agreed to by the parties that INSIM would be adapted to the AECB's HP-1000 and used as the operating environment for the required simulation program for use by the AECB, all at no extra cost.

4. Computation Requirements

The INSIM operating environment had been developed by the Contractor for use on an IBM PC/XT. The INSIM program was adapted for operation on the AECB's HP-1000 computer. SLISIM was developed for operation in the INSIM environment. The source code is written in FORTRAN 77.

As part of the contract, the Contractor installed the SLISIM program on the AECB's HP-1000 computer assisted by the AECB staff.

4.1 HP-1000

The HP-1000 has a multi-user, multi-tasking capability which is accomplished by partitioning the 448K of available memory to a maximum 32K block available to any single user for execution of his program. Programs such as SLISIM which require large amounts of data can be accommodated by storing the data in an extended memory addressing (EMA) location.

However, data stored in EMA cannot be accessed by named common declarations in the various program subroutines. Any data stored in EMA which is accessed by a subroutine has to be treated as blank common. This resulted in a significant increase in the number of declaration statements and extensive changes in the formal parameters of the subroutines required for the SLISIM version for the HP-1000.

The faster speed and the multi-tasking capability of the HP-1000 compared to the IBM PC/XT results in a significant decrease in execution time.

C. RESULTS

The systems logic interaction simulation (SLISIM) program developed by the Contractor and installed on the AECB's HP-1000 computer has been checked against the limited amount of available test data. No significant discrepancies resulted. Because of the limited amount of available test data, not all features available in the SLISIM modules could be checked out in detail. In addition, because of the extensive nature of the SLISIM program, not all possible model configurations and parameter values have been checked out.

Acknowledgements

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